



### BMDO Fiber-Optic Technologies for Telecommunications



Cover photographs:

Top: Vertical cavity surface emitting laser, courtesy of Coretek, Inc.

Center: Optical amplifier, courtesy of Lucent Technologies.

Bottom: A spray of optical fiber emitting visible light, courtesy of Corning, Inc.

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### INTRODUCTION



The first optical fibers lost 99 percent of a light signal within 30 feet. Thanks to developing photonic technologies, light signals can now be transmitted hundreds of miles down hair-thin glass.

"When individuals have [megabits per second of bandwidth], telephone service should cost about three cents a month."

> —Francis McInerney, "Bandwidth, Unlimited," *Scientific American*, January 1997.

Technology change alters the way we look at the world. In a less technological past, humankind was isolated in its communication. Independently developed languages were incomprehensible to other peoples. The convergence of communication—like the blending of Norman French and Anglo Saxon—usually came with the price of conquest. The movement of armies conquered the barriers of place. Today, the pressure of convergence is so great that the once-conquering French have convened governmental bodies to defend their language from the onslaught. Technology is freeing communication from the limits of time and place.

One of the primary communications technologies today is fiber-optic telecommunications. Fiber-optic telecommunications is the transmission of an optical signal by modulating a beam of laser light and sending it down an optical fiber. The modulated beam carries tens of gigabits of data per second and travels intercontinental distances down a hair-thin fiber of glass. This report presents technologies in two major subsystems required for optical transmission of the signal. The first group is optical amplifiers, which amplify the signal about every 50 kilometers so the signal can travel long distances. The second group of technologies applies to wavelength division multiplexing (WDM). Coherent modulation allows the multiplexing of several signals onto the same fiber, which multiplies the capacity of existing fiber. WDM technology is needed to route, track, and switch the multiple signals.

Technology change can often be marked in plateaus. Periodically, an enabling technology combines synergistically with a group of predecessor technologies and raises the level of capability in an industry. Since 1990, telecommunications has witnessed the raising of the plateau, particularly with optical amplification and WDM technologies. The Ballistic Missile Defense Organization (BMDO) has contributed to these technology leaps. BMDO investments made many years ago in WDM technology are showing up in WDM systems available for commercialization today. Basic research in lasers from the early days of the Strategic Defense Initiative Organization (SDIO, BMDO's predecessor) underpins the technology of many of today's laser manufacturers and their suppliers. Research in the rare-earth elements showed up in erbium-doped fiber amplifiers and may be part of future optical amplifiers for other wavelengths besides 1,550 nanometers. Defense work has spun off many light-handling technologies that are reshaping telecommunications.

Technology change also means business opportunity. As the stock markets reflect, telecommunications is a wildcatter's market. Fortunes are made (Ciena), new replaces old (WorldCom), some technology solutions go on to greatness (optical amplifiers), and others are pushed from the mainstream (multimode fiber). Some of the technologies that follow in this report are, or will be, part of the future of fiber-optic telecommunications.

All the technologies presented in this report received some support from BMDO. At the end of each technology description, a company point of contact is listed. Those points of contact are available for discussions leading to the use, integration, manufacturing, and other synergistic partnering of these advanced technologies. Which of these technologies represent the future depends on the creative visions of technologists today.

For further information or to contact technology transfer specialists who can field questions about technologies relating to fiber optics and other commercial applications, please contact:

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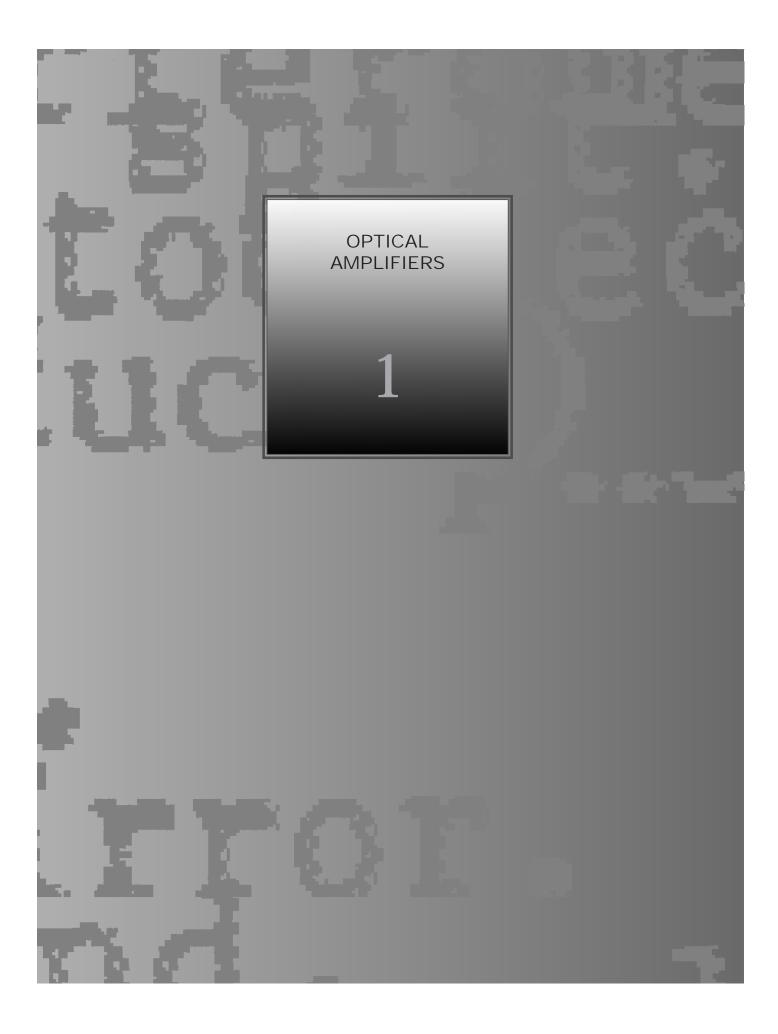
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### OPTICAL AMPLIFIERS MAKE THE DIFFERENCE

### Introduction

Telecommunications companies initiated the transition from copper wire to optical fiber in the 1990s on the strength of the advantage optical amplifiers gave to fiber optics. Simpler, more reliable, and less expensive than electronic repeater systems, optical amplifiers are replacing electronic repeaters in the long-haul backbone and transitioning telecommunications systems from electrical to optical. Repeaters require any light signal to be converted from light to electricity and back to light again to amplify it. Optical amplifiers enable signals to stay in the optical domain, traveling twice as far as optical or electronic signals with conventional repeaters. They can maintain a cleaner signal with higher signal-to-noise ratio, increasing the distance the signal can travel before amplification and making available more of the bandwidth capacity of optical fiber. Amplifiers unleash a tremendous amount of capability for long-distance telecommunications with the flexibility to accommodate technology advances. The amplifiers are used in cable TV optical fiber, long-haul telecommunications networks, and transoceanic submarine cables. With optical amplifiers, loss of signal over distance is no longer the constraining technical limitation.

The lucrative telecommunications systems market has, so far, been penetrated by only one type of optical amplifier operating in one narrow wavelength window, between 1,535 and 1,560 nanometers. These first amplifiers, erbium-doped fiber-optic amplifiers (EDFAs), take advantage of a specific property of erbium, a rare-earth element. Erbium gets excited (i.e., its trivalent ions are raised to a higher energy level) when it is pumped with light at a wavelength near 1,550 nanometers, one of the optimum windows for transmitting light over fiber.

EDFAs consist of a short strand of erbium-doped glass spliced into the main fiber. (Doping replaces a few atoms in a layer of multilayered crystal.) The erbium-doped strand of fiber receives light energy from an external laser diode that pumps light into the fiber, and the strand then acts as a laser in its own right. The new light emission stimulated in the strand is coherent with and therefore amplifies the signal passing down the main fiber, regardless of whether it is single, multiple, digital, analog, high speed, or low speed.

For a successful optical amplifier subsystem, all the components have to come together: the diode laser that pumps the amplifier; the components that couple devices and fiber with little loss of signal; and the light-sensitive, rare-earth-doped fiber. BMDO sponsored research in lasers, optics, laser communications, optical networking, and rare-earth doping that led to essential components and new designs for optical amplifiers.

### **State of The Technology Sector**

The market for optical amplifiers is growing as the technology penetrates new sections of the fiber-optic equipment industry. The amplifier market for fiber systems was \$1.87 billion in 1996, according to a Frost and Sullivan report in the fall of 1997. The report projected market growth at 5 percent per year through 2003 with optical amplifiers gaining an increasing percentage. Because of optical amplifiers, optical fiber has

"The cheap and compact alloptical amplifier . . . is an
invention comparable
in importance to the integrated circuit. Just as the integrated circuit made it possible to put an entire computer
system on a single sliver of
silicon, the all-optical amplifier
makes it possible to put an
entire system on a seamless
seine of silica—glass."

—George Gilder, "Fiber Keeps Its Promise," Forbes ASAP , April 7, 1997.



In telecommunications networks, fibers of ultrapure glass transmit voice, data, and video communications as digital signals emitted by semiconductor lasers the size of a grain of sand. The equivalent of 300,000 telephone calls have been sent over a single fiber.

surpassed satellites as the technology of choice for transoceanic telecommunications. Optical amplifiers are responsible for increasing the rate of transmission from 280 megabits per second on transoceanic cable in the 1980s to 5 gigabits per second for cables under construction in 1997.

A great deal of territory remains that could benefit from optical amplification. Once a reliable pump for optical amplifiers in the short-haul wavelength range (1,330 nanometers) is found, optical amplifiers can penetrate the section of the market servicing the shorter fiber lines in high-traffic areas like cities.

The growing penetration of optical amplifiers into the telecommunications market brings with it increases in transmission rates. It brings fiber-optic technology closer to the promise of all-optical networking. In 1991, Bell Laboratories researchers demonstrated that an all-optical network would have a carrying capacity about 100 times greater than an electronically amplified network. Optical amplifiers remove one electronic bottleneck restricting fiber's speed—the repeater.

Other photonic components must increase in capability to address the increasing capacity of fiber-optic networks. BMDO-funded technologies featured in this section rise to the challenge. E-TEK (page 8) offers a new in-line isolator that allows optical amplifiers to amplify a wide range of wavelengths. Optigain (page 9) and Coherent (page 10) are developing products to extend optical amplifiers into new segments of optical fiber networks. Better, higher power lasers are being offered by SDL (page 11) and Spire (page 12) to meet the telecommunications requirements of the future.

### **Conclusion**

Optical amplifiers have profoundly affected optical communications system architectures and the telecommunications infrastructure. They are simpler, more reliable, and less expensive than electronic repeater systems and make more bandwidth available in optical fiber. Erbium dominates as the rare-earth element used in fiber amplifiers, but researchers are searching for dopants that will operate at other useful wavelengths or across a range of wavelengths to increase the benefits of optical amplifiers to other parts of the network.



E-TEK sells its isolator for EDFAs to Lucent, Alcatel, and other equipment manufacturers that supply companies such as AT&T, Sprint, and MCI.

Developed during a sensor program for BMDO, the E-TEK isolator captured over half of an expanding EDFA market within a year of its introduction. E-TEK's new isolator is poised to capture its share of the expanding WDM market.

### E-TEK PULLS OUT THE STOPS

E-TEK Dynamics, Inc. (San Jose, CA), has developed a new wideband isolator that is a critical component of wideband optical amplifiers. E-TEK is a major supplier of polarization-insensitive fiber isolators (PIFIs) that reduce the loss of power and signal in EDFAs by minimizing signal back reflection. Without this component to keep the signal-to-noise ratio high, amplifying a signal would be like faxing a fax of a fax: the quality decreases each time the signal is amplified. E-TEK's new isolator increases the window on the number of wavelengths an amplifier can amplify. The potential of wavelength division multiplexing is limited by the bandwidth capacity of optical amplifiers. To keep up with the present bandwidth usage increase of 36 percent a year, technology must advance quickly. E-TEK's new isolator helps remove one potential stop to future high-capacity transmissions.

### **Technology Description**

Optical fiber isolators prevent one network component from optically disturbing another, while transmitting signals between them. Polarization variation in fiber-optic components can cause signal loss, so polarization-insensitive fiber isolators are critical to optical amplifiers. In fact, it has been said that PIFI characteristics dominate the performance of submarine cable fiber amplifiers. The isolator uses a Faraday rotator, magnet, polarizer, analyzer, and two collimators. It employs a wedge polarizer that uses polarized rays normal to the incident plane of the birefringent wedge to reduce back reflection. E-TEK's new wideband isolator has a high 45 decibels of isolation with only 0.7 decibels of insertion loss and almost no polarization mode dispersion over a spectrum range of 90 nanometers.

### **Technology Development and Transfer**

BMDO awarded E-TEK a Phase II SBIR contract to develop a fiber-optic sensor system for tracking ballistic missiles, featuring a wide field-of-view (more than one hemisphere), quick response time, low noise, and the ability to track multiple targets. In addition, the company leveraged research and development contracts from NASA, the Air Force, and the Army to further develop its components. The company was successful because it introduced a product with the properties the EDFA market needed—polarization insensitivity, compactness, and low back reflection—just as the market was first emerging. Now the company supplies most of the amplifier manufacturers that supply the major telecommunications companies.

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### OPTIGAIN EXPLORES THE RARE-EARTH ELEMENTS

Erbium dominates as the rare-earth element used in fiber amplifiers, but researchers are working with other rare-earth elements in the search for dopants that will operate at other useful wavelengths or across a range of wavelengths. Rare-earth dopants for fiber-optic amplifiers and lasers are a specialty of BMDO-supported Optigain, Inc. (Peace Dale, RI). Optigain previously demonstrated an EDFA pumped at 800 nanometers by a laser diode. It has also worked on a praseodymium-doped fluoride fiber-optic amplifier



Active fiber devices doped with rare-earth elements reduce power loss and noise in optical systems.

Technology Description
Rare-earth elements, such as po

Rare-earth elements, such as praseodymium, terbium, thulium, erbium, and erbium-terbium, are good electrical conductors and react readily with non-metals. Doping a silica or heavy metal fluoride glass host fiber with a rare-earth element renders the fiber optically active. Active amplification devices like EDFAs are compatible with passive fiber devices like couplers and switches. Many rare-earth dopants can be incorporated in silica and fluoride optical fibers to build a variety of fiber-optic amplifiers and lasers. These devices can be used as light sources, power amplifiers, line amplifiers, and preamplifiers in fiber-optic systems, keeping the signal in the optical domain without electronic conversion and reducing power loss and noise in optical systems.

### **Technology Development and Transfer**

(PDFA) that operates in the 1,300-nanometer band.

Optigain developed the innovative EDFAs for BMDO on SBIR contracts to improve optical communications capabilities. The research contributed to development in lasers and superfluorescent sources that also received funding from the Navy and the Air Force. The company manufactures and sells a range of EDFAs commercially. It also makes thulium and erbium-terbium amplifiers for the 800-nanometer band. The company is developing commercial applications for these amplifiers.

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"Optical amplifiers do for fiber optics and photonics what the transistor did for electronics."

> —Steve Bastien, Optigain.

### Courtesy of Corning. Inc.

Without optical amplifiers that operate in the 1,300-nanometer wavelength range, existing shorthaul lines limit the advantages of fiber optics.

Coherent's laser technology provides a cost-effective source that is an alternative to diode laser sources limited by power and brightness.

### COHERENT PACKS POWER INTO A LITTLE PACKAGE

With the acquisition of the assets of Micracor, Inc. (Acton, MA), in December 1996, Coherent Inc. (Santa Clara, CA) has a lead on a new pump laser that would offer higher power and multiple wavelengths for telecommunications amplifiers. This higher power source could be a pump for the 1,330-nanometer wavelength of praseodymium-doped fiber-optic amplifiers (PDFAs) and the 1,550-nanometer wavelength of EDFAs. A new PDFA pump laser would enable the use of PDFA amplifiers and extend the speed of optical transmission into another segment of the fiber-optic telecommunications network. In addition, new higher power pumps with multiple wavelength capability would enable optical amplifiers to transmit up to 64 channels in a large-bandwidth fiber for the cable television and telecommunications markets, leveraging the capability promised by new WDM technology. The new optical amplifiers could amplify all the wavelengths simultaneously without separating them into individual channels, as opposed to single-wavelength optical amplifiers or electronic repeaters on hybrid coaxial cable that would have to detect and process each wavelength of light individually.

### **Technology Description**

At the heart of Coherent's new pump laser is an optically pumped semiconductor (OPS) laser that offers the size, cost, and reliability of diode lasers with the beam quality of expensive solid-state lasers. The OPS laser can be tuned to different frequencies. It can operate at either 980 or 1,017 nanometers, which correspond to pump wavelengths for PDFAs and EDFAs.

EDFAs operate at 1,550 nanometers in the long-haul segment of the fiber-optic backbone, which is optimized for low signal dispersion (scattering) and less attenuation (the weakening of a signal as it travels). Existing lines in telecommunications distribution hubs and short-haul lines use high-dispersion fiber optimized for 1,330-nanometer transmission. These lines are integrated with the copper wire and hybrid co-axial cables to the home and to the office, where signals are still amplified using repeaters. This environment limits the advantages of fiber as long as no optical amplifier is commercially available that operates at 1,330 nanometers.

### **Technology Development and Transfer**

BMDO funded Micracor to develop smaller, lighter lasers with higher power and better beam quality for communications and space applications. Coherent's new pump laser would provide a cost-effective source that is an alternative to diode laser sources. The company is developing a product that would meet the requirements of the telecommunications environment.

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### SDL DEVELOPS A NEW LASER DESIGN

In May 1998 SDL, Inc. (San Jose, CA), announced a new type of distributed feedback (DFB) laser diode that emits a coherent output power 20 to 100 times greater than conventional lasers. The high-power, single-frequency laser diode has the potential to be an efficient EDFA pump at its standard 976-nanometer wavelength. It can also be made at 1,020 nanometers for pumping PDFAs. Monolithic laser diodes have not previously been able to achieve this diode laser's stable, single-frequency 500 to 1,000 milliwatts. With the ability to deliver a high-quality, high-power output, these compact laser diodes could be used for satellite communications, laser printing, pumping light emitters, laser surgery, and materials processing.

### **Technology Description**

The SDL-6752 series diode lasers use angled-grating DFB technology that SDL calls "Alpha-DFB." The diode incorporates an angled diffraction grating that locks the broadarea laser emission into a single spatial and temporal mode. Emitting directly from the chip, the single-mode laser delivers continuous-wave optical power in a collimated, diffraction limited, circular beam. The beam is single frequency with a linewidth narrower than 5 megahertz. The first devices have been demonstrated at wavelengths ranging from 920 to 1,060 nanometers, but the new design features a low-cost structure applicable to all semiconductor laser materials that emit from the visible (630-nanometer) to mid-infrared (2,000-nanometer) wavelengths. In addition, the laser design can be integrated with other optoelectronic components. The design also permits monolithic integration in arrays.

### **Technology Development and Transfer**

BMDO awarded SDL an SBIR contract to develop higher power, more coherent laser light for satellite laser communications. The compact laser diodes that resulted are useful fiber-optic amplifier laser pumps and sources for spectroscopy. While the technology is still maturing, the first commercial products resulting from this program, the SDL-6752 Alpha-DFB line, are now available. SDL may qualify the laser for telecommunications-standard reliability once the technology is more mature.

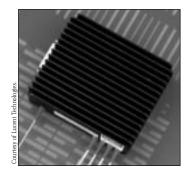
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A 16.4 percent growth in the diode laser market for 1998 is projected by Laser Focus World's 1998 annual market analysis.



A standard telecommunications EDFA includes a pump laser as well as optical and electrical connectors.

### SPIRE PUMPS UP THE VOLUME



Spire Corporation's single and multibar high-power diode laser arrays provide reliability and high power for EDFAs.

Lasers drive growth in the photonics markets as they improve in power output and reliability through better growth of materials and better designs. Telecommunications lasers accounted for \$1.2 billion of 1997's \$3.22 billion domestic sales, according to Laser Focus World.

Spire Corporation (Bedford, MA) supplies metallorganic chemical vapor deposition (MOCVD)-grown optoelectronic epitaxial wafers and components to companies that build lasers and optical amplifiers. Under a requirement to develop more temperature-stable laser diodes for avionics, Spire developed a reliable, high-power indium gallium arsenide (InGaAs) laser diode structured to emit light at 970 nanometers. Diodes fabricated from such material can pump EDFAs used to amplify the signal in cable and telephone communications

vstems.

### **Technology Description**

Advances in epitaxial growth of complex semiconductor wafers in the 1990s have made it possible to fabricate new generations of high-performance optoelectronic devices. Spire specializes in thin films grown by low-pressure MOCVD. The company's research under a BMDO SBIR contract enabled it to improve the epitaxial layer quality and thereby produce epitaxial wafers for more reliable, higher power diodes.

### **Technology Development and Transfer**

Spire received a BMDO SBIR contract to develop an InGaAs laser diode for avionics. Outgrowths of this research were the development of a 970- to 980-nanometer line of epitaxial wafers, as well as the ability to manufacture processed wafers and laser diodes from these wafers. Spire sells epitaxial wafers of the material to laser manufacturers and also sells high-power laser diode bars made from these wafers. The InGaAs laser bars can be used to pump EDFAs.

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WDM TECHNOLOGIES

### WDM MULTIPLIES TELECOMMUNICATIONS CAPACITY

### Introduction

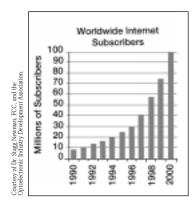
In the last year, telecommunications bandwidth demand increased by about 36 percent on a rapidly increasing growth rate curve. Wavelength division multiplexing (WDM) technology has been embraced in the last two years to meet the demand. WDM allows the graceful upgrading of the fiber-optic network without replacing optical fiber. WDM sends multiple channels of data-carrying light beams down a fiber at the same time, each at a slightly different wavelength, increasing the capacity of the fiber by 100 percent for each additional wavelength. Multiplying the channel capacity of a single optical fiber can help satisfy the exponentially expanding demand for greater bandwidth over the telecommunications network.

The Innovative Science and Technology (IS&T) program within the Science and Technology Directorate at the Ballistic Missile Defense Organization (then the Strategic Defense Initiative Organization) began to focus on WDM technology in about 1990, predicting its future importance. In the military world, one would like to use many channels to send one message quickly. Telecommunications companies would like to have a single physical channel carry many different messages simultaneously. Both multiplexing schemes can be approached by separating the data streams by wavelength. WDM technology's broader bandwidth capacity enables both of these applications. Now industry competition is driving the technology forward, and some of BMDO's investments are paying off. This section presents six stories of companies with cutting edge technologies that are becoming available to the communications market for WDM applications.



1996 was labeled the Year of the WDM at the 1996 Newport Conference on Fiberoptics Markets by keynote speaker Herwig Kogelnik, director of the Lucent Technologies Photonics Research Laboratory at Bell Laboratories. He pointed out that while integrated circuits have progressed tenfold in the last decade, lightwave systems have progressed a hundredfold. Electronicast Corporation predicted in 1997 that such progress would explode the WDM market from \$100 million in 1995 to \$12 billion by 2005. In 1996, Ciena Corporation made an impressive initial public offering based on its WDM technology. "WDM is adding a new dimension to telecommunications, changing the way networks are designed, and creating a need for an array of new technologies," according to Kogelnik.

WDM technology has already had an impact on the industry. At the 1996 Conference on Optical Fiber Communications in San Jose, three companies announced WDM technologies that permitted terabit-per-second transmission down a single fiber. Sprint announced deployment of a WDM system by Ciena that can increase the capacity of a single fiber by 1,600 percent. As pointed out in an April 1997 *Forbes ASAP* article on the "telecosm" revolution, MCI in 1996 had increased the speed of its Internet backbone from 45 megabits per second to 1.2 gigabits. At the beginning of 1997, MCI announced the installation of WDM equipment to increase the speed of its phone network backbone to 40 gigabits per second from 45 megabits per second, a total of a thousandfold upgrade within 36 months. Since then, Ciena has announced technology allowing 100 gigabits-per-second transmission.



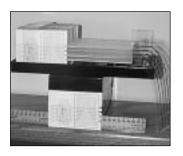
The Internet is one driver of bandwidth demand. While numbers of Internet users are growing, so is individual usage. Also, Internet software applications like streaming video are consuming more bandwidth.

"The law of the telecosm ordains that the total bandwidth of communications systems will triple every year for the next 25 years...In essence, as frequencies rise and wavelengths drop, digital performance improves exponentially. Bandwidth rises, power usage sinks, antenna size shrinks, interference collapses, error rates plummet."

—George Gilder, "Fiber Keeps Its Promise," Forbes ASAP, April 7, 1997. BMDO-funded companies are addressing that "need for an array of new technologies." In the previous section of the report, a new EDFA component isolator by E-TEK (page 8) allows wider bandwidth transmission for optical amplifiers. In this section of the report, a new laser by CoreTek (page 23) allows precise tuning to multiple wavelengths. Ortel (page 22) is selling a new laser array transmitter for WDM transmission. On the application side, Eagle Optoelectronics (page 20) has a system to utilize the greater bandwidth for local area networks (LANs). Mendez Research & Development Associates (page 18) has a scheme to reduce delays caused by switching and transmission protocols.

### Conclusion

"As recently as three years ago, people were still thinking WDM was a niche market," said Alan Willner, BMDO-funded researcher at the University of Southern California. "It is a technology that will upgrade the entire fiber-optic base." Multiplexing increases the capability of fiber-optic networks, making it possible to more fully use the installed base of optical fiber. Adding technology for parallel communications, analogous to parallel processing in computers, promises a tremendous increase of bandwidth in fiber. As the number of channels that can be sent down one fiber increases, bandwidth becomes a cheap resource to be exploited to benefit telecommunications users everywhere.



With only four WDM wavelength channels, MRDA's system can support more than 32 concurrent network users at full bandwidth. The mockup of the WDM/CDMA Hybrid shows the tree topology and ribbon fiber architecture of the system.

"Photonics will transform the [telecommunications] industry by effectivelymaking bandwidth freeand distance irrelevant."

—Peter Cochrane, "Bandwidth, Unlimited," Scientific America, January 1997.

### MULTIPLE USERS ACCESS GREATER TOTAL BANDWIDTH

Mendez R&D Associates (MRDA; El Segundo, CA) is developing WDM/CDMA Hybrid technology that increases the total amount of data transmitted over fiber-optic LANs. The technology combines WDM, associated with telecommunications, and optical code division multiple access (CDMA), associated with data communications. The combined technology greatly expands the number of users that can concurrently access the LAN and reduces delays in data transmission.

### **Technology Description**

MRDA's technology uses a CDMA coding scheme that assigns a combination of wavelengths and pulse positions to each user in the network. This acts as a WDM "wavelength multiplier," increasing the number of users that can access the network simultaneously. Unlike time division multiple access (TDMA), the Hybrid technology does not require network synchronization. It overcomes the limitations of conventional technology by allowing multiple users simultaneous access without having to cue requests or synchronize transmission, thereby reducing transmission-protocol-related delays, as well as switch-induced delays. The Hybrid supports all modes of operation—point-to-point, multicast, and broadcast. The encoder and decoder components can be based on standard WDM transceiver components or adapted to TDMA or WDM telecommunications add-drop multiplexers.

### **Technology Development and Transfer**

With BMDO SBIR contracts and matching funds from the State of California's Office of Strategic Technology and the private sector, MRDA is developing prototype hardware for application in clustered and distributed high-performance computing. MRDA plans to use planar lightwave circuit technology to enhance functional integration, minimize fiber-optic cables and harnesses, and reduce the size of the encoders and decoders to that of a network interface card. MRDA seeks to license or transfer the technology to a firm with foundry, distribution, and marketing capabilities.

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The WDM four-channel signal generator (top left) drives the lasers (foreground), whose output is multiplexed through the WDM system, the black box on the right, and connected with multimode fiber on a spool at the back in this model.

WDM sales will increase from \$1.6 billion in 1997 to \$4.4 billion by 2001, according to Photonic Networks, a report by Ryan, Hankin, Kent Inc. Sales triple in thenext four years as local-exchange carriers join long-distance firms in adopting WDM.

### **GRIN CAN BEAR IT**

WDM technology is limited by the loss of signal from the coupling between the fiber and the WDM device and the range of separation between wavelengths. Radiant Research, Inc. (Austin, TX), is working with the Microelectronics Research Center at the University of Texas (Austin, TX) and LightPath Technologies, Inc. (Albuquerque, NM), to produce a wavelength tunable WDM device that solves these problems. The device is a complementary combination of advanced components and novel optoelectronic packaging. The same device can be custom manufactured to multiplex any one of the three different wavelength bands—800 nanometers; 1,330 nanometers; and 1,550 nanometers—simply by using a different gradient-index (GRIN) lens and holographic grating components. The device is designed to dramatically increase the capacity of one strand of optical fiber to carry data, voice, and video transmissions.

### **Technology Description**

The device uses a holographic grating coupler to fan out (or in) multiple light beams for multiplexing (or demultiplexing). The separated light beams are focused down to the 9-micron width of a strand of fiber by an axial GRIN GRADIUM® lens from LightPath. LightPath uses a new technology to manufacture glass with a changing refractive index for the precise, aberration-free focus required by small fibers. The Microelectronics Center is contributing a waveguide that lengthens the propagation distance and easily accommodates all the existing wavelength separations. Radiant is stacking the lens and a holographic grating into a coupling that increases the number of wavelengths that can be redirected. The coupling employs a compact surface-normal configuration whereby light enters and exits perpendicular to the surface of the waveguide. The surface-normal configuration enhances the packaging reliability enough to withstand the harsh environment of space and is compatible with vertical cavity surface emitting laser arrays that could transmit dozens of optical signals at once.

### **Technology Development and Transfer**

Interested in expertise in BMDO-funded research in waveguides, LightPath approached the Microelectronics Center with just the right component to combine with the waveguide for a novel WDM system design. Radiant, the Microelectronics Center, and LightPath received a Small Business Technology Transfer (STTR) contract from BMDO to develop a WDM prototype. STTR contracts go to businesses partnered with universities. BMDO is interested in space-qualified fiber optics for satellite-to-satellite laser communications and optical sensors as well as optical interconnects for high-speed distributed supercomputing for massive data processing. The companies are looking for manufacturing partners among telecommunications integrators.

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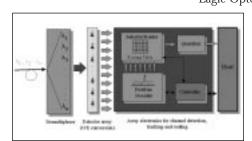
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### EAGLE LEVERAGES LAN CAPACITY



Eagle Optoelectronics' system increases the efficiency of converting photonic WDM signals to electronic signals for computer processing.

The deployment of WDM systems into access networks in the United States will rise from \$76 million in 1998 to \$1 billion by 2003, according to Pioneer Consulting in Fiber Optics News, May 25, 1998.

Eagle Optoelectronics, LLC (Boulder, CO), is making a fiber-optic receiver for short-haul, 850-nanometer-wavelength LANs. The receiver will multiply the capacity of the LAN to simultaneously move a wide range of data through an optical fiber network. Office environments are increasingly dealing with data-intensive office applications like intranets, multimedia, telecommuting, Internet surfing, and video conferencing that demand greater data transmission quickly. Eagle envisions the receiver as a computer card plug-in that demultiplexes incoming optical signals so that separate channels can be tracked and routed according to a translation table for each node of the network. The system can accommodate multiple protocols including ATM,

Sonet, TCP/IP, and Fibre Channel, thus leaving corporate departments' options open.

### **Technology Description**

The receiver is part of a demultiplexer that monolithically integrates the incoming fiber, the receiver's photodetector array, and electronic circuitry. As a multiple-channel signal comes in, the "intelligent" receiver locks on to different transmission wavelengths and tracks any wavelength drift. The receiver uses an optical dispersion component at the front end that is based on a small optical free-space grating. The photodetector array converts the photonic data into electronic signals. The data is stored, translated, and routed by algorithms according to a translation table that stores wavelength position conversion information for each node of the network. Information for the table is collected during system initialization and updated periodically as the system is switched into "decode" mode to correct for any drift in source laser transmission. The receiver obtains its routing data from this table and uses it to send the data to the host.

### **Technology Development and Transfer**

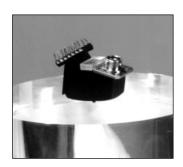
Eagle's intelligent receiver was funded in part by BMDO and Department of Energy SBIR contracts. The robust device can be used for fiber optics in harsh conditions including airplanes and launch environments. Eagle plans a release of a test four-wavelength receiver for LAN routers in 1998. Following the router, Eagle plans to release the plugin intelligent receiver card. The company is looking for strategic partnerships with OEM manufacturers, particularly low-cost die-level packagers, for licensing the technology.

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ORNL's rugged, single-structure microspectrometer can do a big job on a microscale, sorting wavelengths separated by only 1.6 nanometers.

ORNL's diamond turning fabrication process can be used to make molds for injection-molding mass production, lowering the manufacturing cost of the microspectometer.

### OPTICAL SPECTROMETER IS THUMB SIZED AND LOW COST

Oak Ridge National Laboratory (ORNL; Oak Ridge, TN) has developed a microspectrometer that is a fraction of the size of most spectrometers. The microspectrometer is an optical device that sorts light according to wavelength. Its small 6-cm³ size and relatively inexpensive manufacturing make it attractive for shorter distance multimode telecommunications and LANs. The high resolution of the microspectrometer is able to resolve channels separated by only 1.6 nanometers. The system has a linear dispersion less than 10 nanometers per millimeter and uses a grating with 1,650 lines per millimeter. Because the device is made as a single structure, it is fully aligned during fabrication and requires no adjustment.

### **Technology Description**

The microspectrometer is a modified Czerny-Turner configuration containing five precision surfaces encapsulated in a single structure. At the entrance surface, light is collected by the optical fiber and directed to the collimating surface. The collimating surface redirects the light toward the grating surface. The grating surface disperses the incident light toward the focusing surface, which intercepts the diverging cone of light and refocuses it.

### **Technology Development and Transfer**

The novel fabrication technique ORNL used to reduce the cost of manufacturing relies on specialized diamond turning equipment originally developed for BMDO through ORNL's Manufacturing Operations Development and Integration Laboratory. Lockheed Martin Energy Research Corporation, ORNL's operator, funded research into a full design using the microspectrometer for an eight-channel WDM system. That design is available for licensing.

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Ortel's new laser array transmitter may provide the company with a stepping stone into digital telecommunications, including telephone and data communications and Internet traffic.

"Thanks to the vision of the BMDO and DOD and the development efforts at Ortel, the research community can now obtain a four-wavelength OC-48 WDM transmitter for less than \$25,000—a price far below anything on the market today."

-John Rinks, Ortel

### ORTEL BRINGS WDM LASER ARRAY TRANSMITTER WITHIN REACH

Ortel Corporation (Alhambra, CA) is offering an affordable four-channel WDM laser array transmitter for fiber optics at less than half the price of anything comparable on the market. The transmitters are designed for WDM systems research like high-speed transmission experiments and testbeds and product development support. The transmitters meet the OC-48 standard (2.4 gigabits per second), which is the fastest widely implemented standard for data rate transmission.

### **Technology Description**

A component of WDM systems for fiber optics, the transmitter integrates cooled and isolated distributed feedback lasers that transmit precise standard telecommunications wavelengths around 1,550 nanometers with 200-gigahertz separation between channels. One four-laser unit fits into a standard 19-inch rack, can be plugged into a wall socket to operate, and is configured for direct modulation.

### **Technology Development and Transfer**

The WDM transmitter was manufactured to meet BMDO's requirements for high-speed networking for a distributed supercomputing testbed. BMDO's Science and Technology Directorate created a demand for this laser transmitter by organizing a mass purchase of the array through a university consortium, the WDM Alliance. Arrays were purchased using part of BMDO's portion of Defense University Research Instrumentation Program (DURIP) funds, which provide research instruments to defense-funded university researchers. The new product is a valuable component for researchers, OEMs, and system integrators to research and test new WDM system architectures.

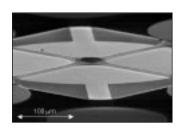
Ortel is delivering the first production units to the WDM Alliance managers for testing before distribution to other universities in the consortium. According to Todd Olson, project engineering manager, the product will provide Ortel with a stepping stone into digital telecommunications, including telephone and data communications and Internet traffic

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In this scanning electron microscope micrograph of CoreTek's tunable VCSEL, the domed mirror is in the circular pattern at the center of the device. They are only visible viewed by interferometric microscopes.

WDM technology establishes a new set of provisioning problems, such as installing one discrete laser for each wavelength used. This provisioning ripples through the entire component supply chain, from manufacturer to field support. Possible solutions involve the use of tunable lasers or disposable wavelengths."

—John Ryan, "WDM Technology Enriches Sales, Networks, and Investments," *Lightwave*, June 1997.

### CORETEK TUNES IN TO WDM TELECOM MARKET

CoreTek, Inc. (Burlington, MA), has a technology called MEM-SEL $^{\text{TM}}$  that can help satisfy the 36 percent growth in demand a year for bandwidth. The company's unique combination of vertical cavity surface emitting laser (VCSEL) technology and microelectromechanical (MEM) technology accesses up to 1,800 different wavelength channels over a 30-nanometer spectrum. The MEM-SEL controls the laser wavelength by integrating movable microelectromechanical mirrors on the chip with the laser. CoreTek's device changes the frequency of the beam without changing the mode for fixed-wavelength applications like WDM or for tuning source lasers for high-speed short-haul networks or LANs.

### **Technology Description**

CoreTek's MEM-SEL has all the advantages of VCSELs, which are miniature semiconductor lasers with high beam quality. Unlike standard edge-emitting lasers, VCSELs can be stacked side by side in two-dimensional arrays for transmitting multiple WDM channels over one optical fiber. Also, they produce nearly circular beams about 10 microns in diameter that diverge very little, which gives them a 90 percent coupling efficiency with fiber-optic cable. The MEM-SEL uses indium gallium arsenide phosphate on indium phosphate (InGaAsP/InP) as the semiconductor gain medium for the laser.

In addition to the advantages of VCSELs, CoreTek's MEM-SEL can be tuned to different wavelengths. The MEM-SEL has a half-symmetric cavity with a curved top mirror that shapes and focuses the lightbeam. Like a tethered microscopic dome, the mirror is moved down toward the substrate as a voltage is applied to the four tethers. The tuning changes the frequency of the beam without changing the mode. Thus any wavelength within the tuning range can be achieved. CoreTek has demonstrated an 850-nanometer MEM-SEL with a 30-nanometer tuning range.

### **Technology Development and Transfer**

CoreTek developed the VCSEL for fast, optically steered, phased-array antennas and high-speed LANs under BMDO SBIR Phase I and II contracts. A patent is pending on the movable confocal spherical surface mirror. CoreTek is looking for partners for fabricating integrated devices.

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